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ORIGINAL CONTRIBUTION

Measuring Environmental Sustainability at Borderland Ports: Development and Validation of a Multidimensional Scale

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Abstract— Borderland ports are vital nodes along land-based trade corridors, but their environmental performance has been under studied and measured. While seaports and dry ports benefit from expanding sustainability indicators, no psychometrically validated instrument exists for evaluating environmental sustainability at borderland ports. This study develops and validates a multidimensional scale for assessing environmental sustainability at borderland ports. Drawing on the port sustainability literature, the United Nations Sustainable Development Goals (SDGs) and the Environmental and Social Framework of the Asian Development Bank (ADB), we conceptualize the construct in terms of eight dimensions: good health and well-being, clean water and sanitation, affordable and clean energy, sustainable cities and communities, responsible consumption and production, climate action, life on land, and partnerships for the goals. A 64-item instrument was administered in two sequential survey waves to stakeholders at Pakistan's three major borderland ports. Principal axis factoring with Direct Oblimin rotation of the first-wave dataset (N = 730) supported the eight-factor structure, with Cronbach's alpha coefficients ranging from .881 to .948. Confirmatory factor analysis of the second-wave dataset (N = 730) supported the correlated eight-factor first-order model (CMIN/DF = 2.769; CFI = .971; TLI = .917; SRMR = .043; RMSEA = .049; PClose = .779), with satisfactory convergent and discriminant validity. Environmental sustainability at borderland ports is thus a coherent, measurable construct, offering governments and development partners a diagnostic and benchmarking tool for greening border infrastructure across the Central Asian Regional Economic Cooperation (CAREC) region.

Index Terms— Borderland ports, Border crossing points, Environmental sustainability, Scale development, Sustainable development goals, Environmental and social framework, CAREC

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Introduction

Borderland ports have emerged as hubs for international trade, complementing traditional maritime gateways, with the increase in dependence on inland logistics networks. The development of transcontinental corridors linking East Asia, Central Asia, South Asia, and Europe has propelled the importance of dry ports, intermodal terminals, and land border crossing points (BCPs), especially within the corridors of the Central Asia Regional Economic Cooperation (CAREC) programme (Bergqvist & Wilmsmeier, 2016; Kalyuzhnova & Holzhacker, 2021; Pomfret, 2019; Roso et al., 2009).

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This increasing economic contribution is paralleled by environmental costs that have not necessarily materialized in trade statistics. Borderland ports handle freight vehicles, cargo handling equipment, inspection activity, and energy-intensive facilities in concentrated locations, and provide an environment that supports high volumes of transient users. The by-products can include vehicle emissions, dust, noise, wastewater, solid waste, and high consumption of energy, and the risks are extended to the surrounding communities and ecosystems. Such pressures are frequently more intense in rural border areas where municipal services and environmental infrastructure and monitoring capabilities are often limited (Bhatti, 2024; Davarzani et al., 2016; Karagkouni & Boile, 2024; Puig et al., 2014).

However, much of the existing knowledge on port sustainability is derived from studies of seaports and dry ports and not of borders. Research on ports has focused on environmental performance indicators, green-port activities, pollution-control measures, and environmental innovations in general (Acciaro et al., 2014; Asgari et al., 2015; Davarzani et al., 2016; Lam & Notteboom, 2014; Puig et al., 2014). Dry ports and inland terminals have explored the issue from a slightly different direction, addressing modal shift, freight consolidation, congestion relief, and the ensuing reduction in emissions due to transport (Hanaoka & Regmi, 2011; Khaslavskaya & Roso, 2019; Lattila et al., 2013; Roso, 2007). A smaller stream of research has focused on the drivers behind inland-port operators' decision to engage in green practice, highlighting institutional pressures as a factor (Oláh et al., 2018; Vejvar et al., 2018).

While the existing literature is indeed very helpful, it does not cover the borderland ports. A borderland port is not a seaport with an inland location, nor is it a dry port near a frontier. More precisely, it is a point of transition of jurisdictions, a point where customs, immigration, security, transport, and terminal-management agencies operate across organizational and national borders simultaneously. The environmental consequences of such a location are not only influenced by the infrastructure and logistics capacity, but also by the inspection procedures, the requirements for documentation, the bilateral arrangements, security considerations, and the quality of coordination between the agencies involved, which are not necessarily under the same authority. These can extend dwell times, render environmental responsibility opaque between actors, and make sustainability outcomes, as much as the operational practice, a matter of the cooperation between institutions (Bhatti, 2024; Hanjra et al., 2025a, 2025b; Kalyuzhnova & Holzhacker, 2021). Measurement tools used at a single-jurisdiction port were not designed to reflect this, and this is evident when they are used at the border.

The gap is not only conceptual but also methodological. Inland logistics sustainability studies are largely based on emission estimates, simulation models, indicator inventories, ranking systems, and multi-criteria decision methods Awad-Núñez et al., 2015; de Almeida Rodrigues et al., 2021; Lattila et al., 2013; Oláh et al., 2018; Roso, 2007. Importantly, at present, no psychometrically validated instrument is available to measure the environmental sustainability of borderland ports. In the absence of one, comparisons amongst the different studies are problematic, theories do not build up as expected, and port authorities do not have a good tool for identifying weaknesses or measuring progress over time (Churchill Jr, 1979; DeVellis, 2017; Hinkin, 1998).

The United Nations Sustainable Development Goals (SDGs) provide a universally accepted framework for action in health, water and sanitation, clean energy, sustainable communities, responsible consumption, climate action, biodiversity and institutional partnerships (United Nations, 2015). Likewise, the Asian Development Bank's (ADB) Environmental and Social Framework takes it a step further: environmental and social risks must also be identified, managed, monitored, and disclosed throughout the project cycle (Asian Development Bank, 2024).

Notably, Pakistan provides a fitting setting in which to take on this gap empirically. Its border facilities are engaged in bilateral and transit trade with its neighbouring countries and are connected to routes of the CAREC and CPEC routes. The three ports examined here, Torkham, Chaman, and Wagah are geographically, climatologically, and in terms of their trade, institutional set-up, and surrounding communities, reasonably challenging conditions for developing and testing a measurement instrument (Bhatti, 2024; Hanjra et al., 2025a, 2025b, 2025c). Pakistan is used here as a context to validate the instrument, not as evidence that it will necessarily generalize to all borders and countries.

Based on this consideration, the study aims to design and empirically validate a multidimensional scale for environmental sustainability for borderland ports. The instrument reflects eight interrelated but distinct dimensions, based on the port sustainability literature, SDGs, and the ADB Environmental and Social Framework: good health and well-being, clean water and sanitation, affordable and clean energy, sustainable cities and communities, responsible consumption and production, climate action, life on land, and partnerships for the goals. The post-EFA data set, consisting of 730 stakeholder responses in total, was used to test the correlated 8-factor structure, as well as internal consistency, convergent validity and discriminant validity, (Byrne, 2016; Churchill Jr, 1979; Fornell & Larcker, 1981; Hinkin, 1998).

This work has led to the following three contributions. The first is conceptual: the paper takes environmental sustainability studies one step further by examining borderland ports, and why their cross-jurisdictional, multi-agency nature merits a tool of its own. The second is methodological: the paper constructs and presents an initial validation of a 64-item instrument with eight correlated but analytically different dimensions, which advances beyond the indicator lists in the literature that are not yet fully validated, and takes the literature another step towards examining factorial structure and psychometric quality. The third is practical: the tool provides a structured approach for port authorities, border agencies, policy makers and development partners to diagnose, plan, monitor, and hold institutions accountable for problems.

Literature Review

Borderland ports as Inland nodes in trade corridors

It is generally argued that a dry port should be regarded as an inland intermodal terminal that is linked directly to one or more seaports via high transport capacity and where customers can unload/load standardized units as if they were at the seaport (Roso & Lumsden, 2010; Roso et al., 2009). In addition to the transshipment function, mature inland nodes offer storage, consolidation, empty container depots, maintenance, and customs clearance (Bergqvist & Wilmsmeier, 2016; Cullinane et al., 2012; Notteboom et al., 2022). The concept has spread across the world, with documented development trajectories in Europe (Oláh et al., 2018), China (Beresford et al., 2012), India (Ng & Gujar, 2009), and Southeast Asian countries (Nguyen & Notteboom, 2016), and a growing research agenda focusing on location analysis, governance, performance, and supply chain outcomes (de Almeida Rodrigues et al., 2021; Khaslavskaya & Roso, 2020).

Borderland ports, also called border crossing points or land ports, are similar to dry ports as they are located inland, have the same intermodal interfaces and customs activities. BCPs have three important characteristics which distinguish them from others. These are the first domains of delegated authority concerning the movement of cargo and passengers across border regions. This involves two national administrations, as well as the coordination of inspections, documentation, and releases within each respective country. Further, their throughput is limited by their physical capabilities, procedural and documentation requirements, as well as security operations (Kalyuzhnova & Holzhacker, 2021). Third, these facilities are often situated in isolated and remote, arid, mountainous regions, far from major towns or urban centers. The ecosystems are experiencing increased vulnerability, coupled with inadequate provision of municipal services, on which communities depend for employment opportunities and infrastructure development. The existing body of literature on seaports and dry ports does not sufficiently capture this complexity, as it is largely based on a single jurisdiction (Banomyong et al., 2026; Hanjra et al., 2025a, 2025b, 2025c).

Studies on the CAREC program indicate that economic corridor development through the transport corridor is critical for the benefits of trade cost reductions (Bhatti, 2024; Bhatti et al., 2025). Soft infrastructure, border procedures and institutional coordination, and regulatory convergence are the missing pieces (Kalyuzhnova & Holzhacker, 2021; Pomfret, 2019). Although it is not operationalized for border facilities, recent research on the end-to-end corridor configuration, including the dry-port to dry-port concept, similarly emphasizes the environmental dimension as an essential performance criterion of inland logistics systems (Van Zanten et al., 2024).

Environmental sustainability of ports and Inland terminals

Davarzani et al. (2016), Lam and Notteboom (2014) and Merk (2013) document the pollution profile of port operations for seaports, covering air emissions, water pollution, noise, dredging effects, and waste. Acciaro et al. (2014) proposed a framework for environmental innovation in seaports, arguing that the greening of seaports requires energy management and the participation of stakeholders. Asgari et al. (2015) ranked major ports based on their sustainability criteria; Lu, Shang, and Lin (2016) analyzed sustainability performances from the point of view of port managers; and Schipper et al. (2017) examined the gap between the sustainability vision and the sustainability outcomes of port-city plans. Likewise, Puig et al. (2014) has identified and prioritized environmental performance indicators for sustainable port development.

Due to favorable network conditions, the use of intensive dry ports can decrease emissions throughout the network by 30–40% (Lattila et al., 2013). The simulation by Roso (2007) showed that the application of a dry port would lead to a carbon dioxide reduction of approximately 25% and a decrease in the queueing of trucks at the seaport. The environmental argument was extended to Asia by Hanaoka and Regmi (2011) who advocated the role of dry ports as instruments to facilitate intermodal freight transportation in developing countries. But environmental management at the inland facility has not received as much attention as modal shift (Khaslavskaya & Roso, 2020; Yin et al., 2023). A benchmarking study on European dry ports identified a range of measures for green logistics, which are currently in place but not evenly distributed across the board, with an average self-assessed frequency of 4.6 on a 10-point scale (Oláh et al., 2018). Although outcome-driven supply chain perspectives identified environmental sustainability as one of the key value propositions of dry ports, Vejvar et al. (2018) found that inland port operators implemented sustainability practices in response to a variety of institutional pressures (Khaslavskaya & Roso, 2019).

Awad-Núñez et al. (2015) specifically interrogated the sustainability of dry port sites and presented a Bayesian network alongside a multi-criteria methodology focused on site selection rather than operational efficacy. None of these contributions successfully validate an environmental measurement model through factor analysis, and none address the context of border crossing.

Policy anchors: The SDGs and the ADB environmental and social framework

The proposed scale is grounded in two distinct policy architectures. The 2030 Agenda for Sustainable Development is characterized by its 17 Sustainable Development Goals (SDGs), representing the most widely embraced framework for evaluating sustainable development within the realms of public policy and management scholarship (United Nations, 2015). Eight objectives are intricately linked to the environmental initiatives of a borderland port: SDG 3, which focuses on good health and well-being; SDG 6, emphasizing clean water and sanitation; SDG 7, advocating for affordable and clean energy; SDG 11, promoting sustainable cities and communities; SDG 12, highlighting responsible consumption and production; SDG 13, addressing climate action; SDG 15, concerning life on land; and SDG 17, which underscores the importance of partnerships

for the goals. It guarantees thorough coverage of the environmental domains affected by BCP activities and presents measurement data in a manner that is readily accessible for governments reporting on SDG targets (Bhatti, 2024; Bhatti et al., 2025).

The second anchor is the newly developed ADB Environmental and Social Framework (ESF) that will replace the 2009 Safeguard Policy Statement and will be applicable to sovereign operations from January 2026 (ADB, 2024). Table I aligns each dimension of the scale derived from the Sustainable Development Goals (SDG) with the corresponding Environmental and Social Framework (ESF) standards, providing a detailed explanation of the links between them.

Table I
Mapping of SDGs, scale constructs, and ADB environmental and social framework (ESF, 2024)

SDG	BCP Sustainability Dimension	Relevant ADB ESF Standard	Linkage
SDG 3 Good Health and Wellbeing	Air Quality and Pollution Control	ESS 3 Resource Conservation and Pollution Prevention; ESS 4 Health, Safety, and Security	Addresses emissions, dust, noise, and health risks affecting workers and communities.
SDG 6 Clean Water and Sanitation	Water Management	ESS 3 Resource Conservation and Pollution Prevention	Covers wastewater, drainage, water conservation, and pollution prevention.
SDG 7 Affordable and Clean Energy	Energy Efficiency	ESS 3 Resource Conservation and Pollution Prevention; ESS 9 Climate Change	Supports energy efficiency, cleaner energy, and lower greenhouse gas emissions.
SDG 11 Sustainable Cities and Communities	Urban Integration and Stakeholder Wellbeing	ESS 4 Health, Safety, and Security; ESS 10 Stakeholder Engagement and Information Disclosure	Supports safe infrastructure and engagement with surrounding communities.
SDG 12 Responsible Consumption and Production	Waste Management and Circular Economy	ESS 3 Resource Conservation and Pollution Prevention	Addresses waste management, resource efficiency, and circular practices.
SDG 13 Climate Action	Climate Resilience and Emergency Preparedness	ESS 9 Climate Change; ESS 4 Health, Safety, and Security	Covers climate risk, mitigation, resilience, and emergency preparedness.
SDG 15 Life on Land	Biodiversity and Ecosystem Protection	ESS 6 Biodiversity Conservation and Sustainable Natural Resources Management	Protects habitats, biodiversity, ecosystems, and natural resources.
SDG 17 Partnerships for the Goals	Governance and Cross Border Partnerships	ESS 10 Stakeholder Engagement and Information Disclosure	Supports transparent engagement, information disclosure, and stakeholder coordination.

Note. BCP = Border Crossing Point; ESS = Environmental and Social Standard; ESF = Environmental and Social Framework. Source: Authors' elaboration based on United Nations (2015) and Asian Development Bank (2024)

Research gap

Three research gaps emerge with regard to the measurement of environmental impact at border land ports. First, there is the contextual gap, indicating that borderland ports have been conceptualized as a peripheral variant of dry ports, and their unique environmental attributes, such as procedural congestion, dual-jurisdiction governance, and frontier ecologies, have not been adequately theorized or quantified. The literature on the sustainability of land-based trade-cargo handling/clearance facilities has been viewed using the lenses of dry ports and inland ports, considering borderland ports one of these categories without examining their peculiarities and specific context. A bibliometric review of 232 papers (2000–2023) shows that most dry-port research concentrates on definition, functions, policy and governance, location analysis, ownership, and dry port–seaport interaction, while dry-port environmental sustainability and their linkage with the SDGs receive comparatively less attention (Beyene et al., 2024). Similarly, a systematic review of inland-port sustainability (2012–2024) identifies a critical need for standardized sustainability metrics and explicit incorporation of the UN SDGs into inland-port assessment, particularly the border land ports due to the larger scale of their activities as compared to dry ports (Shayan & Mohabbati-Kalejahi, 2026). Similarly, where border facilities are measured, the instruments are oriented to trade efficiency rather than environmental performance, for instance the recently validated Border Performance Index, assesses border operations with no environmental dimension included (Banomyong et al., 2026). Corridor-level assessments likewise operationalize border performance through compliance time and cost indicators rather than ecological outcomes (Wang et al., 2024). These findings remain isolated and facility specific. No study theorizes borderland ports as a distinct construct whose environmental performance differs from that of seaports or ordinary dry ports (Sharma et al., 2026; Stewart et al., 2023).

Second, there are methodological gaps in assessing the environmental effect of inland trade facilities. The dominant approaches seem to follow three directions: simulation models (e.g., queueing simulations of border wait times and emissions) (Stewart et al., 2023), indicator inventories fed into non-parametric efficiency models (e.g., Global Reporting Initiative indicators and a DEA eco-efficiency frontier for seaports) (Bulak, 2024), and multi-criteria indicator catalogues for green-port evaluation (Na-Nan et al., 2024). A systematic review of 67 port-sustainability studies (2014–2024) confirms that these literatures remain fragmented (Shabib et al., 2025). These approaches have not fully adhered to the

standards of measurement and scale development literature and lack in formal construct definition, item generation and purification, exploratory and confirmatory factor analysis, and reliability and validity testing (Fei et al., 2025; Sharma et al., 2026).

The third gap is institutional, where environmental performance disclosures are demanded by regional and global institutions for border land ports without any clear and well-defined criteria/ instrument (Almeida & Okon, 2026). On the SDG side, the port industry has begun to localize the 2030 Agenda through 69 SDG targets, spanning all 17 goals (Tremblay et al., 2025). However, this operationalization stops at seaports; it has not been extended to borderland ports or border crossing points. Though the environmental and social frameworks of multilateral development and financial institutions like ADB specify ESG requirements for financial support/ lending, yet they lack the measurable sustainability focus of international rating systems (Rodríguez Estévez & Arce Ruíz, 2024). The result is an institutional gap created by the disharmony between SDGs and ESF in relation to environmental performance at border crossing points. The current investigation seeks to address all three identified gaps by developing and validating a scale for environmental sustainability specifically tailored to borderland ports, in accordance with the Sustainable Development Goals.

Conceptual Framework

The Environmental sustainability of a borderland port is characterized by the extent to which the port's infrastructure, processes, and institutional structures safeguard human health, conserve nature, reduce pollution, and climate related risks, and facilitate coherent action at the organizational and national level. In line with indicator-based approaches in sustainability research in ports and the SDG's construction, environmental sustainability is considered a multidimensional measurement domain with distinct, but related, areas of environmental performance (Lu et al., 2016; Puig et al., 2014; United Nations, 2015).

The framework is grounded in eight SDGs relevant to the activities of borderland ports. These are Good Health and Wellbeing, Clean Water and Sanitation, Affordable and Clean Energy, Sustainable Cities and Communities, Responsible Consumption and Production, Climate Action, Life on Land, and Partnerships for the Goals. Each dimension is associated with an operational domain that represents observed practices and conditions at a border crossing point. The 8 domains are Air Quality and Pollution Control, Water Management, Energy Efficiency, Urban Integration and Stakeholder Wellbeing, Waste Management and Circular Economy, Climate Resilience and Emergency Preparedness, Biodiversity and Ecosystem Protection, and Governance and Cross Border Partnerships. Their alignment with the relevant Environmental and Social Standards under the Asian Development Bank is showcased in Table I (Asian Development Bank, 2024).

Good Health and Wellbeing is represented by air quality and pollution control, especially in relation to port operations impacting workers, transport operators, and surrounding communities (Davarzani et al., 2016; Hanaoka & Regmi, 2011). Clean Water and Sanitation focuses on the management, conservation, and protection of water resources (Puig et al., 2014). Affordable and Clean Energy focuses on energy efficiency and moving towards alternative and cleaner energy sources (Acciaro et al., 2014; Oláh et al., 2018). Sustainable Cities and Communities considers the relationship between port activity, surrounding communities, urban conditions, and stakeholder wellbeing (Lam & Notteboom, 2014; Roso et al., 2009; Schipper et al., 2017).

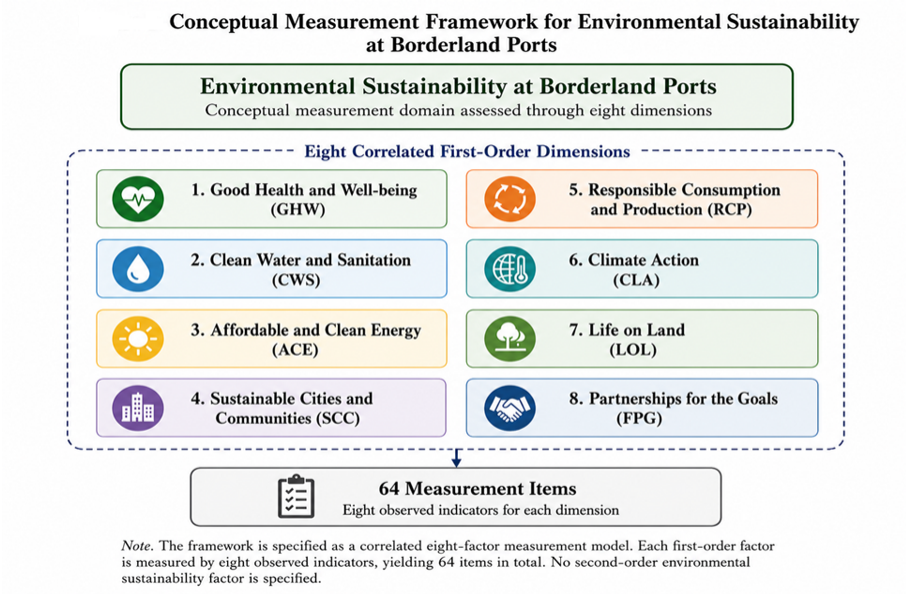

Fig. 1 *Conceptual framework*

Responsible Consumption and Production focuses on issues relating to waste management, sustainable procurement, and circular economy practices (Davarzani et al., 2016). Climate Action incorporates climate risk assessment, mitigation, resilient infrastructure, and emergency preparedness (Asian Development Bank, 2024; Lattila et al., 2013). Life on Land refers to biodiversity, ecosystem protection, and land degradation issues related to port activity (Asian Development Bank, 2024; Roso, 2007). Partnerships for the Goals reflects governance and cooperation among public agencies, transport actors, communities, research institutions, and other actors involved in environmental decision making (Bergqvist & Wilmsmeier, 2016; Kalyuzhnova & Holzhacker, 2021).

The measurement model specifies eight correlated first order reflective factors. Notably, each factor is measured by eight observed indicators resulting in a total of 64 items. The factors are allowed to covary as environmental practices at borderland ports are operationally and institutionally interconnected. Similarly, each factor remains conceptually distinct and is interpreted separately. No second order environmental sustainability factor is specified.

Methodology

Instrument development and content validity

The scale development was based on a deductive paradigm, which is recommended when the concept has a clear theoretical and policy basis (Churchill Jr, 1979; Hinkin, 1998). The domain of each of the eight dimensions was defined by the SDG targets associated with it, the requirements of the relevant ESF standards (Asian Development Bank, 2024), and the port and inland terminal sustainability literature reviewed earlier. The items were then extracted and adapted from existing indicator sets and management practices documented in that literature, such as buffer zoning, emission control, and dust suppression (Davarzani et al., 2016; Karagkouni & Boile, 2024; Puig et al., 2014); green logistics measures, such as energy-efficient lighting, photovoltaics, and environmental certification (Oláh et al., 2018); environmental decision criteria for inland facilities (de Almeida Rodrigues et al., 2021); and mechanisms for stakeholder engagement and cross border cooperation (Kalyuzhnova & Holzhacker, 2021; Van Zanten et al., 2024).

A pool of 64 items was created by writing eight items for each dimension. To help respondents base their assessment/opinions on operational reality rather than abstract attitudes, each item was phrased as a specific, observable practice or condition at the borderland port. Content and face validity were established through an expert review coordinated by the Project Management Unit of the CAREC RIBS program. An expert panel consisting of customs and border management officials, environmental safeguard specialists, logistics practitioners, and academics reviewed the item pool and assessed the clarity, relevance, comprehensiveness and fitness/compatibility of the items with the operational realities of BCPs.

Items were rated on a six-point Likert type scale from 1 (strongly disagree) to 6 (strongly agree). A six-point forced choice format was preferred over a five- or seven-point format to reduce the likelihood of neutral midpoint response, which is common among officials judging their own facilities, and to increase discrimination at the agreement end of the continuum (DeVellis, 2017). The data were collected from the three major land border ports of Pakistan in different provinces, namely, Torkham in Khyber Pakhtunkhwa, and Chaman in Balochistan along the Pakistan-Afghanistan border and Wagah in Punjab along the Pakistan-India border.

Participants in the study comprised stakeholders who possess direct and ongoing engagement with port operations. This group included officials from customs and border agencies, management personnel from terminals and ports, clearing and forwarding agents, transport operators and drivers, as well as traders active in or near the border crossing points (BCPs). The participants of the current research are in line with the main decision makers and stakeholders in the dry port literature (de Almeida Rodrigues et al., 2021; Nguyen & Notteboom, 2016). The empirical validation for the current Study was conducted through two sequential data collection waves. The first-wave dataset consisted of 730 usable responses and was utilized for exploratory assessment and internal consistency of the proposed 64-item instrument.

Subsequently, a second round of data collection was conducted after the completion of the exploratory stage. The same respondents were recontacted as the population of stakeholders holding direct and sustained knowledge of borderland port operations at the selected BCPs was institutionally specialized and limited. Therefore, the second round of data collection generated a new post EFA data set rather than reusing the responses analyzed during the exploratory stage. In fact, the second wave also included 730 usable responses and was used exclusively for confirmatory factor analysis and the assessment of convergent and discriminant validity. Self-administered questionnaires were distributed on-site as part of a structured survey of the three ports, with the assistance of an enumerator as a source of clarification. Participation was voluntary and anonymous, and respondents were told that there was no right or wrong answer, and that their responses would only be used in aggregate for research and policy development purposes.

Notably, the use of separate survey administration presented the researchers with temporal separation between the exploratory and confirmatory stages. Nevertheless, as the same specialized respondents were contacted again, the design does not constitute cross-validation using a completely independent respondent population.

Common method considerations

As the present study relied on the stakeholder assessment collected through the same instrument within each data collection wave, procedural safeguards were incorporated to reduce the risk of common method bias (Podsakoff et al., 2003). Harman's single-factor diagnostic was conducted

by entering all 64 items into an unrotated exploratory solution and examining the proportion of variance accounted for by the first factor. To minimize evaluation apprehension, anonymity and confidentiality were assured; items were phrased as statements of facts about observable practices rather than as evaluations of management; dimension labels were not provided in the questionnaire; and the instrument was reviewed by experts to eliminate ambiguous and leading formulations.

Analytical strategy

The psychometric evaluation was carried out in two sequential empirical stages based on the two separate survey stages. First, the factorability of the correlation matrix was assessed by the Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy Kaiser and Bartlett's test of sphericity. Exploratory factor analysis (EFA) was performed with Principal Axis Factoring (PAF) using Direct Oblimin rotation. PAF was selected because the objective was to identify the common latent structure underlying the measurement items. An oblique rotation (Direct Oblimin) was used due to the expected theoretical correlation of the eight environmental sustainability dimensions. This specification was in accordance with recommendations for EFA of correlated latent dimensions (Fabrigar et al., 1999; Goretzko et al., 2021). Cronbach's alpha was used to test internal consistency, with a .70 cut-off point recommended by Nunnally and Bernstein (1994). In the second wave dataset, the measurement model was then subjected to confirmatory factor analysis with maximum likelihood estimation in IBM SPSS AMOS 23.0 (Byrne, 2016). The CFA model stipulated eight correlated first order reflective factors. No second order environmental sustainability factor was specified or tested in this study.

Model fit was assessed based on the combined criteria of Hu and Bentler (1999) used in the relevant literature (Gaskin & Lim, 2016; Kline, 2016), which included the normed chi-square (CMIN/DF), the Comparative Fit Index (CFI), the Tucker–Lewis Index (TLI), the standardized Root Mean Square Residual (SRMR) and the Root Mean Square Error of Approximation (RMSEA) with its PClose statistic. The indices were considered jointly rather than depending on any single threshold as the main basis for evaluating the model adequacy. Likewise, internal consistency in the confirmatory dataset was assessed using Cronbach's alpha, while Average Variance Extracted (AVE) was used to assess convergent validity. Discriminant validity was calculated using the Fornell and Larcker criterion by comparing the square root of each factor's Average Variance Extracted (AVE) with its correlations with the remaining factors (Fornell & Larcker, 1981). Also, reliability and validity were evaluated separately for each of the eight first order factors. Notably as the same respondents participated in both survey administrations, temporal stability was additionally assessed using intraclass correlation coefficients (ICC; two-way mixed-effects model, absolute agreement) for the eight dimension-level composite scores across the two waves.

Results

Data screening and factorability

A total of 1200 questionnaires were distributed to the stakeholders in the public and private sectors in the three borderland ports. A total of 730 were returned and usable in the analysis, resulting in a usable response rate of 60.8%. Notably, these 730 responses constituted the first wave dataset and were used for data screening, exploratory principal axis factoring, and internal consistency assessment. Data were screened for univariate normality prior to the analysis. The skewness values of all constructs were found to be within the range of +1/-1 and the kurtosis values within the range of +2/-2, which are well with the accepted norms. In addition, analysis of histograms confirmed the approximately normal distribution of the data. The sample of 730, after screening, was found to be a ratio of 11.4:1 observations to items, which is acceptable for factor analysis (Hair et al., 2010) and larger than the 500 recommended by Comrey and Lee (1992) as a very good sample size.

The respondent profile also validated the sample's appropriateness for scale validation. By gender, the respondents were 53% male and 47% female. In terms of educational qualifications, 50% of the respondents had bachelor's degrees, 32% had master's degrees, and the remaining 18% had doctoral qualifications. With regard to professional experience, 75% of the respondents had more than 10 years of relevant experience. All the respondents were directly involved in trade, logistics, and borderland port operations. They included representatives from Customs, Terminal operation, Plant and animal quarantine, Trading communities, Immigration, Security agencies, and Infrastructure specialists. According to the profile, the data was collected from stakeholders with knowledge of operational, institutional, and environmental aspects of borderland ports.

The factorability of the correlation matrix was verified by two diagnostics. The overall Kaiser–Meyer–Olkin measure of sampling adequacy was .913, which far exceeded the recommended value and indicated a commendable measure of sampling adequacy (Kaiser, 1974). The Bartlett test for sphericity was statistically significant (approximate χ^2 = 41,502.341, df = 2,016, $p < .001$) and thus the hypothesis that the correlation matrix was an identity matrix was rejected (Bartlett, 1950). Together, the findings obtained endorsed that the Wave 1 dataset was suitable for exploratory factor analysis.

Table II
Sample adequacy and sphericity test

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.913
Bartlett's Test of Sphericity	Approx. Chi-Square	41502.341
	Df	2016
	Sig.	.000

Exploratory factor analysis

Exploratory factor analysis (EFA) was performed with Principal Axis Factoring (PAF) using oblique rotation (Direct Oblimin). Factor retention was assessed using the eigenvalue criterion, inspection of the scree structure, theoretical interpretability, and parallel analysis. The first eight observed eigenvalues were 11.642, 8.006, 6.011, 4.879, 4.458, 3.293, 2.700, and 2.018. The ninth eigenvalue declined to .922. In parallel analysis, the observed eighth eigenvalue (2.018) exceeded the corresponding 95th-percentile random eigenvalue (1.423), whereas the observed ninth eigenvalue (.922) fell below its corresponding random eigenvalue (1.399). The retained eight-factor solution was supported by the eigenvalue pattern, parallel analysis, theoretical interpretability, and the rotated factor structure (Hair et al., 2010).

The Direct Oblimin solution produced an interpretable eight-factor pattern. All 64 items loaded primarily on their theoretically specified factors, and the retained item loadings were of practically meaningful magnitude (Hair et al., 2010). A few items yielded modest communalities, such as .482 for item RCP5 and .507 for item CLA2, but all were retained at the exploratory stage. This decision was made based on three considerations: (1) each item loaded substantially on the target factor; (2) deletion would have jeopardized the careful eight-item balance within dimensions and, accordingly, the complete representation of the Sustainable Development Goal targets and Environmental and Social Framework requirements; and (3) the data had been collected with an extensive multi-site field effort, and the information value argued for not prematurely trimming. Instead, the level of refinement applied to items was deferred to the confirmatory stage, when any changes could be evaluated based on clear fit criteria. Table III presents the communalities and Direct Oblimin pattern loadings of all 64 items.

Table III
Exploratory factor analysis of the environmental sustainability scale: communalities and direct oblimin pattern loadings

items	Commonality	Loadings on Factors							
		Factor-1	Factor-2	Factor-3	Factor-4	Factor-5	Factor-6	Factor-7	Factor-8
GHW1	.957	.980							
GHW2	.703	.733							
GHW3	.692	.713							
GHW4	.663	.692							
GHW5	.769	.854							
GHW6	.681	.710							
GHW7	.783	.846							
GHW8	.659	.672							
CWS1	.686		.808						
CWS2	.643		.790						
CWS3	.698		.818						
CWS4	.746		.738						
CWS5	.649		.809						
CWS6	.852		.921						
CWS7	.722		.720						
CWS8	.824		.910						
ACE1	.774			.856					
ACE2	.602			.779					
ACE3	.639			.759					
ACE4	.719			.672					
ACE5	.655			.833					
ACE6	.654			.816					
ACE7	.921			.902					
ACE8	.806			.891					
SCC1	.674				.817				
SCC2	.731				.539				
SCC3	.780				.565				
SCC4	.786				.749				

Cont.....

items	Commonality	Loadings on Factors							
		Factor-1	Factor-2	Factor-3	Factor-4	Factor-5	Factor-6	Factor-7	Factor-8
SCC5	.708				.642				
SCC6	.694				.664				
SCC7	.859				.950				
SCC8	.698				.684				
RCP1	.678					.660			
RCP2	.731					.856			
RCP3	.634					.774			
RCP4	.972					.977			
RCP5	.482					.652			
RCP6	.929					.969			
RCP7	.974					.984			
RCP8	.912					.942			
CLA1	.722						.719		
CLA2	.507						.627		
CLA3	.607						.695		
CLA4	.690						.622		
CLA5	.617						.572		
CLA6	.916						.957		
CLA7	.639						.790		
CLA8	.661						.719		
LOL1	.646							.783	
LOL2	.749							.641	
LOL3	.897							.936	
LOL4	.679							.682	
LOL5	.866							.903	
LOL6	.657							.647	
LOL7	.626							.671	
LOL8	.603							.729	
FPG1	.779								.743
FPG2	.766								.680
FPG3	.755								.670
FPG4	.656								.671
FPG5	.709								.837
FPG6	.610								.788
FPG7	.721								.828
FPG8	.662								.672

Note. Wave 1, *N* = 730. Extraction method: principal axis factoring. Rotation method: Direct Oblimin. Factor 1 = Good Health and Well-being; Factor 2 = Clean Water and Sanitation; Factor 3 = Affordable and Clean Energy; Factor 4 = Sustainable Cities and Communities; Factor 5 = Responsible Consumption and Production; Factor 6 = Climate Action; Factor 7 = Life on Land; Factor 8 = Partnerships for the Goals.

Reliability

Table IV
Reliability of the environmental sustainability dimensions

Number	Construct	Number of items	Cronbach's alpha
1	Good Health and Well-being	8	.924
2	Clean Water and Sanitation	8	.938
3	Affordable and Clean Energy	8	.940
4	Sustainable Cities and Communities	8	.913
5	Responsible Consumption and Production	8	.948
6	Climate Action	8	.881
7	Life on Land	8	.919
8	Partnerships for the Goals	8	.904

The Internal consistency showcased a robust strength throughout the instrument. As indicated in Table IV, Cronbach's alpha values varied from .881 for Climate Action to .948 for Responsible Consumption and Production, with each dimension surpassing the general acceptable threshold of .70 as well as the more rigorous criteria .80 benchmark (Nunnally & Bernstein, 1994).

Confirmatory Factor Analysis

The confirmatory analysis was carried out by employing the second wave data set. The data set comprised of 730 usable responses which were collected through a separate survey administration after completion of the exploratory-stage. Importantly, the same stakeholder population was recontacted, the second wave responses were collected newly and were not used for the principal axis factoring. The hypothesized measurement model, comprising eight correlated first order factors representing the eight dimensions of environmental sustainability, was estimated in IBM SPSS AMOS 23.0 using maximum likelihood estimation. The model fits the data well. The fit statistics are reported in Table V against the thresholds compiled by Gaskin and Lim (2016) and Hu and Bentler (1999). The CFA measurement model is depicted in Figure 2.

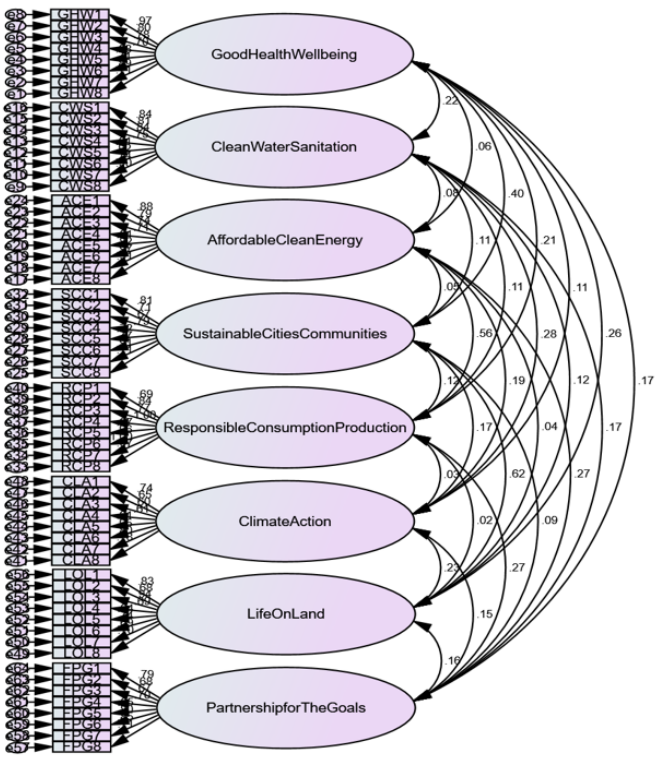

Fig. 2 *Confirmatory factor analysis measurement model.*

Table V
Model fit indices – Environmental sustainability eight factors model

Measure/Index	Estimate	Threshold			Interpretation
		Acceptable	Good	Excellent	
CMIN	5327	-		-	-
DF	1924	-		-	-
CMIN/DF	2.769	≤ 3 to ≤ 5	≤ 2 to ≤ 3	< 2	Good
CFI	.971	.90 to .94	.95 to .97	≥ .97	Excellent
TLI	.917	.90 to .94	.95 to .97	≥ .97	Acceptable
SRMR	.043	.08 to .10	0.05 to 0.08	<.05	Excellent
RMSEA	.049	.06 to .08	0.05 to 0.06	<.05	Excellent
PClose	0.779	≥ .05	> .10 to 0.50	>.50	Excellent

Note: Model fit indices were evaluated jointly rather than based on any single criterion. Guidelines follow Gaskin & Lim (2016) and Hu & Bentler (1999), and Kline (2016). The model chi square is reported for completeness because of its sensitivity to large samples.

Convergent and discriminant validity

Convergent validity was assessed through the Average Variance Extracted (AVE) for each construct, along with the Cronbach's alpha values as detailed in Table IV which consisted of the results of data collected in first wave. Table VI contains results of data analysis of second wave and explains that the standardized factor loadings, AVE values for all constructs exceeded .50, and the reliability for each construct surpassed .70. These findings affirm that the eight-factor measurement model exhibits strong convergent validity, as supported by Fornell and Larcker (1981).

Table VI
Standardized item loadings, average variance extracted and internal consistency by construct

Construct	Items	Standardized Loadings								AVE	Cronbach's Alpha
		Factor-1	Factor-2	Factor-3	Factor-4	Factor–5	Factor-6	Factor-7	Factor-8		
Good Health and Well-being										.629	.921
GHW1	.970										
GHW2	.783										
GHW3	.761										
GHW4	.679										
GHW5	.866										
GHW6	.688										
GHW7	.876										
GHW8	.669										
Clean Water and Sanitation										.671	.934
CWS1			.825								
CWS2			.800								
CWS3			.832								
CWS4			.739								
CWS5			.800								
CWS6			.917								
CWS7			.722								
CWS8			.897								
Affordable and Clean Energy										.674	.942
ACE1				.873							
ACE2				.773							
ACE3				.719							
ACE4				.696							
ACE5				.799							
ACE6				.808							
ACE7				.961							
ACE8				.902							
Sustainable Cities and Communities										.583	.908
SCC1					.805						
SCC2					.701						
SCC3					.695						
SCC4											.784
SCC5					.712						
SCC6					.770						
SCC7					.910						
SCC8					.707						
Responsible Consumption and Production											.742 .946
RCP1						.683					
RCP2						.815					
RCP3						.748					

Cont.....

Construct	Items	Standardized Loadings								AVE	Cronbach's Alpha
		Factor-1	Factor-2	Factor-3	Factor-4	Factor–5	Factor-6	Factor-7	Factor-8		
RCP4						.998					
RCP5						.637					
RCP6						.954					
RCP7						.998					
RCP8						.967					
Climate Action										.580	.876
CLA1							.724				
CLA2							.631				
CLA3							.685				
CLA4							.719				
CLA5							.791				
CLA6							.951				
CLA7							.793				
CLA8							.758				
Life on Land										.658	.917
LOL1								.826			
LOL2								.779			
LOL3								.936			
LOL4								.791			
LOL5								.936			
LOL6								.736			
LOL7								.708			
LOL8											.742
Partnerships for the Goals										.601	.904
FPG1									.772		
FPG2									.764		
FPG3									.748		
FPG4									.780		
FPG5									.838		
FPG6									.779		
FPG7									.834		
FPG8									.674		

The discriminant validity was assessed utilizing the Fornell–Larcker criterion, as shown in Table VII. For each construct, the square root of the Average Variance Extracted (AVE), as indicated on the diagonal, surpassed the correlations of that construct with all other constructs. This finding supports the presence of discriminant validity among the eight dimensions of the scale.

Table VII
Discriminant validity: Fornell–Larcker criterion

Factors	GHW	CWS	ACE	SCC	RCP	CLA	LOL	FPG
Good Health and Well-being (GHW)	.793							
Clean Water and Sanitation (CWS)	.52	.819						
Affordable and Clean Energy (ACE)	.47	.54	.821					
Sustainable Cities and Communities (SCC)	.49	.58	.51	.764				
Responsible Consumption and Production (RCP)	.46	.55	.59	.53	.861			
Climate Action (CLA)	.43	.51	.62	.56	.58	.762		
Life on Land (LOL)	.48	.50	.46	.54	.55	.60	.811	
Partnerships for the Goals (FPG)	.44	.49	.52	.61	.57	.55	.53	.775

Note. Diagonal values in bold are the square roots of the average variance extracted; off-diagonal values are inter-construct correlations. Discriminant validity is supported, as each square-root AVE exceeds the construct's correlations with all other constructs (Fornell & Larcker, 1981). *N* = 730.

Since the Fornell–Larcker criterion may not identify all discriminant-validity problems, the heterotrait–monotrait ratio of correlations (HTMT) was also examined as an additional diagnostic (Henseler et al., 2015). All pairwise HTMT values remained below the conservative .85 criterion

(Table VIII). The highest HTMT value was .654, providing additional support for the empirical distinctiveness of the eight dimensions.

Table VIII
Heterotrait–Monotrait (HTMT) ratios

Dimension	GHW	CWS	ACE	SCC	RCP	CLA	LOL	FPG
GHW	—							
CWS	.151	—						
ACE	.414	.088	—					
SCC	.382	.078	.137	—				
RCP	.178	.051	.478	.054	—			
CLA	.083	.242	.108	.154	.129	—		
LOL	.261	.085	.106	.654	.106	.188	—	
FPG	.050	.046	.168	.038	.183	.077	.104	—

Note. Wave 2, *N* = 730. HTMT values below .85 provide conservative evidence of discriminant validity (Henseler et al., 2015).

Comparison with competing unidimensional measurement model

Given the correlated first-order structure, the validation was strengthened by testing an alternative model (fully unidimensional model). A single undifferentiated environmental sustainability factor was estimated using the 64 indicators/items. This comparison directly tested whether the multidimensional representation provided a materially better account of the observed covariance structure. The unidimensional model performed substantially worse than the hypothesized correlated eight-factor model. The pronounced deterioration in fit under the unidimensional specification provided direct evidence that the 64 indicators should not be represented by a single undifferentiated factor. Harman's single-factor diagnostic was examined separately from the competing CFA model. The first unrotated factor accounted for 18.19% of the total variance, indicating that no single factor dominated the covariance structure. This diagnostic is interpreted together with the procedural safeguards rather than as definitive evidence that common method bias is absent (Podsakoff et al., 2003).

Table IX
Comparison of the eight factor model and competing unidimensional Model

Model	χ^2	Df	CMIN/DF	CFI	TLI	SRMR	RMSEA
Correlated eight-factor model	5,327.00	1,924	2.769	.971	.917	.043	.049
Unidimensional one-factor model	32,025.30	1,952	16.406	.263	.239	.209	.145

Note. Wave 2, *N* = 730. Both models were estimated using the same 64 observed indicators. The comparison was conducted to determine whether a single-factor representation could adequately account for the data relative to the theoretically specified correlated eight-factor structure.

Test – retest reliability check

To assess the stability of the 64-item questionnaire and the resultant responses, test-retest reliability was evaluated using data collected from the same sample of respondents (*N* = 730) across two distinct waves having an interval of eight weeks. Composite scores were computed for each of the eight dimensions (consisting of 8 items per dimension) at both time points. Intra-class Correlation Coefficients (ICC; two-way mixed, absolute agreement) were calculated for each dimension. The test-retest coefficients ranged from 0.87 to 0.94, with all values being statistically significant ($p < 0.001$).

Discussion and Conclusions

Theoretical implications

Three theoretical implications follow. First, it expands the scope of port sustainability research. The greening literature has moved from a focus on seaports (Acciaro et al., 2014; Lam & Notteboom, 2014) to include dry ports and inland terminals (Khaslavskaya & Roso, 2019; Roso, 2007), but borderland ports have yet to be introduced into the conversation. By conceptualizing the BCP as a special type of infrastructure, an inland node where the environmental performance is shaped by the infrastructure, operations, and cross-jurisdictional governance, respectively, this study provides a basic conceptualization for future theoretical work on the sustainability of border infrastructure. The importance of the partnerships dimension of the validated model is particularly relevant here: at a border, the environmental outcomes are inherently tied to inter-agency and inter-state cooperation, a relationship that is not captured by the single-jurisdiction port models.

Secondly, this study addresses persistent demands within the inland logistics literature for the integration of measures. de Almeida Rodrigues et al. (2021) noted that environmental criteria are dispersed throughout various studies and assigned weights in an arbitrary manner; Awad-Núñez

et al. (2015) illustrated the necessity for sustainability measurement, albeit limited to decisions regarding location. The current framework consolidates these varied indicators into a unified, psychometrically robust structure, thereby transforming a catalogue of criteria into a theoretical measurement model. Third, the dual anchoring strategy, which derives dimensions concurrently from a global normative framework (the SDGs) and from an operative safeguard regime (the ADB ESF), presents a transferable template for construct development in various infrastructure domains.

Policy and managerial implications

For policymakers and development partners, the scale provides what safeguard frameworks assume but does not deliver: a practical tool to assess environmental performance at the facility-level. Each dimension translates into specific ESF standards (Table I), so scale scores can directly inform the environmental assessment, monitoring, and disclosure requirements that the ESF will require for ADB financed operations from 2026 (Asian Development Bank, 2024). Currently, measurement of corridor performance in the CAREC program is based on time and cost indicators. An environmental dimension can be added to corridor measurement to serve as a complement to this framework and help governments track the extent to which border modernization efforts also support environmental sustainability. This provides an opportunity for the regional harmonization of environmental standards, which has been identified as a key priority in corridor scholarship (Kalyuzhnova & Holzhacker, 2021; Pomfret, 2019).

For port authorities and border management agencies, the multi-dimensional framework translates measurement into actionable management and administration. Notably, the measurement scale can help to prioritize investments, create training programs, and assign accountability across all border agencies.

Limitations and future research

The contributions of this study should be evaluated considering its limitations, each of which also presents opportunities for future research. Firstly, the data were obtained by two successive administrations of a survey involving stakeholders' perceptions. Procedural remedies were included in the design to minimize the risk of common method bias (Podsakoff et al., 2003). While the evidence of an interpretable eight-dimensional structure and the evidence for discriminant validity do not appear to support the presence of a single dominant response pattern, findings cannot entirely rule out common method bias. Therefore, any perception-based score should be confirmed by objective measurements like air-quality measurements, energy-consumption records, and wastewater-test results.

Secondly, exploratory and confirmatory analyses have been conducted using two separately gathered datasets from the same expert stakeholder population. The approach consequently does not represent cross-validation utilizing a completely independent respondent sample. A logical next step is to examine measurement invariance across ports, stakeholder categories, and countries. Validation of the measurement model by an independent sample, ideally from a different CAREC member country, may enhance confidence in its applicability (Byrne, 2016).

Third, the nomological network of the construct is still not delineated, although evidence exists for dimensionality, internal consistency, convergent validity, and discriminant validity. Future research could examine the scale's criterion-related and predictive validity and situate the scale in meaningful frameworks that relate environmental sustainability to important borderland-port outputs, including trade facilitation performance, community health, worker safety, and border operation resilience to climate shocks. Fourth, this study was conducted within the context of Pakistan. While the three ports surveyed are geographically distinct and have different trade characteristics, the institutional, legal, and policy environment is common to the entire research area. Comparative applications of the instrument across the CAREC member countries would verify the cross-national portability of the instrument and give additional insights into the effects of institutional quality on environmental performance across country boundaries.

Conclusion

Borderland ports aggregate the environmental burdens associated with overland trade at the intersections of national jurisdictions; however, they have been deficient in meeting even the fundamental prerequisite for effective environmental governance: a reliable method for assessing performance. This study established and validated the initial multidimensional environmental sustainability scale specifically for borderland ports. It is grounded in eight dimensions aligned with the Sustainable Development Goals and the Asian Development Bank's Environmental and Social Framework. The structural integrity of the scale was confirmed through both exploratory and confirmatory factor analyses, utilizing data collected from 730 stakeholders at Pakistan's three main land border crossings. The instrument demonstrates reliability, factorial and convergent validity, and its double policy anchoring facilitates its use for safeguard compliance, corridor monitoring, and cross-country benchmarking. As governments and development banks allocate resources towards the transformation of transport corridors into economic corridors, the magnitude of this initiative provides an opportunity to ensure that the transformation is also environmentally sustainable, with metrics that are measurable, comparable, and accountable.

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